VARIATIONS IN THE ANNUAL FREQUENCY OF TROPICAL CYCLONES, 1886–1958 [1]

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ABSTRACT

In this investigation the annual frequency data for typhoons and hurricanes during the 1886–1958 period are examined in search of cycles, trends, and space correlations. The results are largely negative. In spite of this fact, it was felt that, for the benefit of other investigators interested in this topic, it might be worth while to outline the analysis procedures followed and to present the results which were obtained. We have taken a rather qualitative approach in our analysis of the hurricane and typhoon data. However, in view of the character of the basic data we doubt that more meaningful results could have been obtained by a strict application of statistical techniques.

1. INTRODUCTION

Climatological records show that the number of tropical cyclones originating in the individual formation areas varies appreciably from year to year. These fluctuations do not appear to be completely random and there are periods as long as 10 years when the average activity in given areas may be significantly above or below the long-term average. The interannual changes in the frequency of tropical cyclones are thought to be influenced to some degree by variations in the characteristics of the large-scale tropospheric flow patterns of the atmosphere [6], [1]. The mean trough and ridge positions and, perhaps to a lesser extent, the strength of the circumpolar circulation often show anomalous features which persist for a whole season or longer [5]. It is reasonable to expect that anomalous features of this type may contribute toward increased tropical cyclogenesis in some areas and toward decreased activity in others. There may be other factors, such as the sea surface temperature, which would influence large areas in the same sense.

Relatively little has been done in correlating the seasonal and longer-term variations in tropical cyclone activity in one geographical area with those found in other areas throughout the world. Studies of this type have undoubtedly been hampered by the lack of comprehensive compilations of tropical cyclone statistics on a world wide basis. Information on tropical cyclone frequencies taken from the track charts prepared by individual meteorological services throughout the world have a number of weaknesses. The data coverage for the ocean areas is much more complete in some areas and during some time periods than in others, and perhaps more important, the classification criteria for tropical cyclones listed in the various sets of track charts have not been standardized.

Within recent years considerable effort has been devoted to the preparation of thoroughly checked tropical cyclone tracks for the Northern Hemisphere portions of the Atlantic and western Pacific Oceans covering periods of about 70 years. With the data available from these track charts, it is now possible to investigate correlations between tropical cyclone frequencies in the Atlantic and Pacific areas and between individual regions within these larger areas. This report presents the results of an investigation of this type.

2. DATA SELECTION

The basic data sources for this investigation have been the recently published tracks of hurricanes [3] prepared by Cry, Haggard, and White [3] and of typhoons prepared by Chin [2]. The individual storm tracks shown in these publications were checked as carefully as possible using various source materials. An attempt was made to separate the tropical cyclones which did not reach hurricane intensity from those which did, and also to indicate the point at which each storm reached hurricane intensity. There is no doubt that subjective judgment was required in many cases in prescribing the tracks and in indicating the storm intensity. However, in view of the effort which went into the preparation of the tracks, we have

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[3] The term "hurricane" will always be used in referring to tropical cyclones in the Atlantic-Caribbean-Gulf of Mexico area and "typhoon" will be used only for tropical cyclones in the western North Pacific-South China Sea area. However, in considering storm strength we will use the term "hurricane intensity" in referring to storms in any area. Tropical cyclones are considered to be of hurricane intensity if the maximum wind speeds exceed 74 m.p.h.

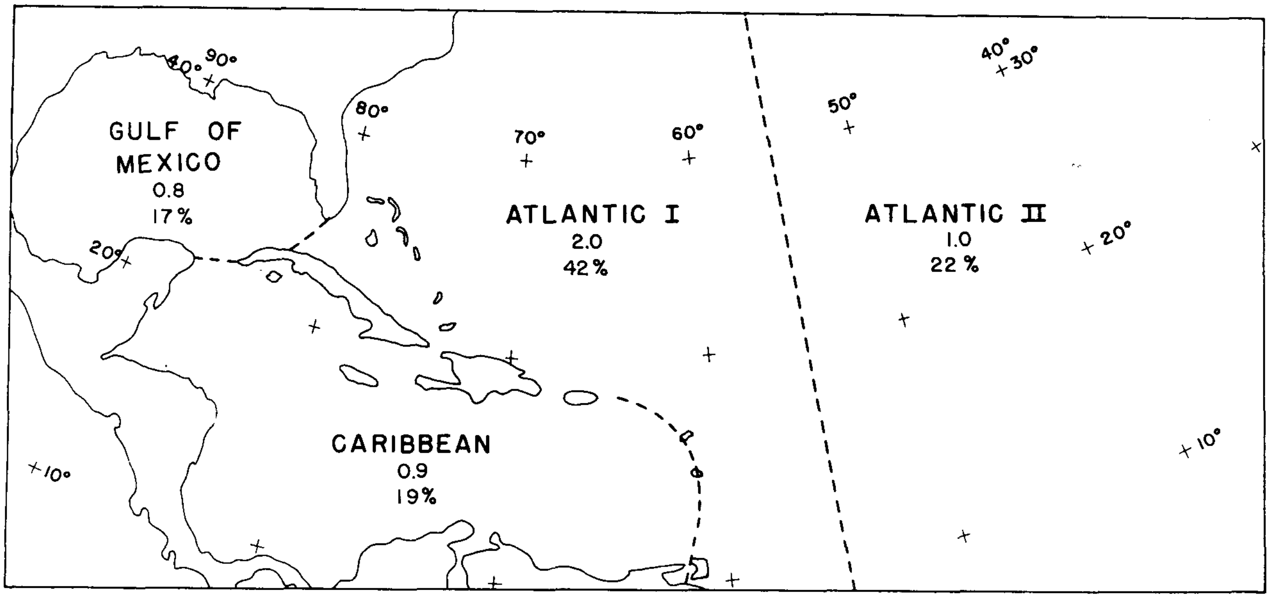

Figure 1.—The Atlantic regional subdivisions used in this study. The average number of storms of hurricane intensity forming in each region during the 1886–1958 period is given immediately below the regional designator. The percentage figures refer to the contribution of each region to the total number of hurricanes.

reason to believe that the completeness, consistency, and accuracy of the information provided are as good as can be expected from the available records.

The synoptic coverage over the ocean areas has improved over the years, especially since the advent of aircraft reconnaissance. Some increase in the reported frequency of tropical cyclones should therefore be expected and this increase would probably be more apparent in the statistics for the smaller and weaker storms than for the larger and more intense ones. In the hope of attaining a more homogeneous data sample, we have restricted our attention to those storms which were shown as having attained hurricane intensity at some time during their life history. There is some question of how much is gained by this restriction since data relating to the intensity and to the place of formation of individual storms are undoubtedly much less reliable during the earlier portion of the record.

The published hurricane tracks [3] cover the period 1886–1958 while the typhoon tracks [2] cover the period 1884–1953. In this study, the period 1886–1958 has been used and we have added typhoon information for the period 1954–1958 from the "Trajectories of Tropical Cyclones" prepared annually by the Japanese Meteorological Agency. For our purposes we have considered the beginning point of the hurricane (or typhoon) portion of the storm track as the formation point.

The areas in the Atlantic and Pacific considered in this study are shown in figures 1 and 2. The two ocean areas have been divided into four regions in a rather arbitrary manner. Statistics on the average number of storms or hurricane intensity per year forming in each of the regions and the percentage contribution of each region to the total storm population of each ocean area are shown on these figures. Some of the regions such as the South China Sea, the Gulf of Mexico, and the Caribbean represent natural geographical divisions. The further division of the Atlantic and Pacific areas (figs. 1 and 2) is arbitrary but, in a rough way the primary formation area in each ocean is separated from secondary formation areas. Nearly two-thirds of the typhoons originate in the Pacific I region and over 40 percent of the hurricanes originate in the Atlantic I region. In the Pacific, we separated out the storms forming at relatively high latitudes, but, primarily because of the smaller number of storms involved, no division of this type was made for the Atlantic.

Data for the Pacific II region cannot be considered very reliable. The tracks prepared by Chin [2] extend only as far east as 150° E., and we have simply assumed that all typhoons crossing this longitude from the east originated in the Pacific II region. In many cases, typhoons forming in this region may have moved into the middle latitudes without moving west of 150° E. and therefore do not appear in our data. There are other reasons, discussed below, for believing that the reliability of the data for the Pacific II region is somewhat less than that for the other regions.

The Atlantic and Pacific areas could, of course, have been divided quite differently than was done in this study and it is possible that more meaningful results could have been obtained by some other division. However, we were not sufficiently encouraged by the results we obtained to experiment with further subdivisions of the Atlantic and Pacific areas or to consider the other tropical cyclone formation areas, i.e., the eastern North Pacific,

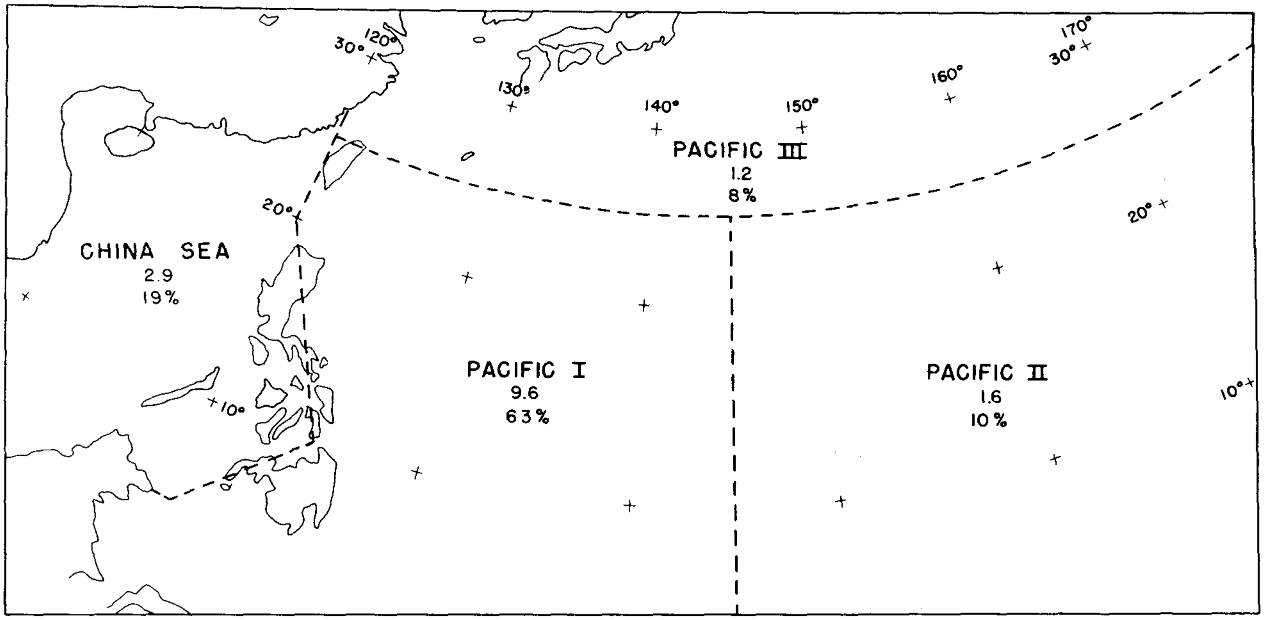

FIGURE 2.—Regional subdivisions for the Pacific area.

the western South Pacific, the Bay of Bengal, Arabian Sea, or the western South Indian Ocean. Inclusion of data from these additional areas would entail a great deal of work since annual frequency statistics are not readily available for extended periods.

3. TROPICAL CYCLONE ACTIVITY IN THE ATLANTIC AND WESTERN PACIFIC AREAS

The total number of tropical cyclones occurring each year over the major ocean areas varies over a fairly large range. This variability is illustrated by the curves of figure 3 which depict the annual number of storms of hurricane intensity which occurred in the complete Pacific and Atlantic areas (figs. 1 and 2) during the period 1886–1958. Activity in the Pacific is normally much greater than in the Atlantic with the respective mean frequencies 15.3 and 4.6 storms per year. Inclusion of weaker storms led to the higher values of 21.1 and 7.3 given for typhoons and hurricanes by Dunn [4] and Riehl [7].

A frequency distribution of the total number of hurricanes per year (table 1) shows a range from 0 to 11 storms with a rather pronounced peak in the distribution. Three or four hurricanes were reported in 28 of the years and more than 70 percent of the years reported from 2 to 6 occurrences. The Pacific statistics (table 1) show a total range from 5 to 37 typhoons with a distribution which has a rather broad plateau with about 75 percent of the years reporting from 11 to 18 storms. It is apparent from the curves in figure 3 that activity in the two ocean areas is not highly correlated. The linear correlation coefficient between the annual frequencies in the two areas is +0.04.

Although the interannual variability shown by the curves in figure 3 is very great, there are cases in both areas when the activity during most years of extended periods has tended to be somewhat above or below the long-term average. In an attempt to bring out some of the longer-term variations, a smoothing of the annual frequencies was carried out by preparing running 5-year means for the two areas (fig. 4). The smoothed curves show, perhaps a little more clearly than those of figure 3, that there has been a definite tendency for an increase in the reported number of hurricanes and typhoons during the last 20 years of the record. At least to some extent, this increase may be due to the increased synoptic coverage over the tropical oceans. However, it is of interest that there has not been a continual trend of this type through the period of record. There was a trend toward decreasing frequencies in the Atlantic which extended from the beginning of the record until about 1910. No such trend is apparent in the typhoon data.

The smooth typhoon curve (fig. 4) shows a number of oscillations with a spacing between adjacent crests and troughs which varies from 5 to 9 years. These oscillations are also apparent in the annual totals (fig. 3). The average period determined from the complete record is about 12 years. Since this is close to the mean sunspot period, an attempt was made to relate the maxima and minima in the typhoon curve with those in the sunspot frequencies. During most of the period of record, typhoons were most frequent during periods of increasing sunspot activity and less frequent during the periods of decreasing activity. However, the period prior to 1895 and that following 1945 do not fit into this pattern. Therefore, we are inclined to think that the fairly close

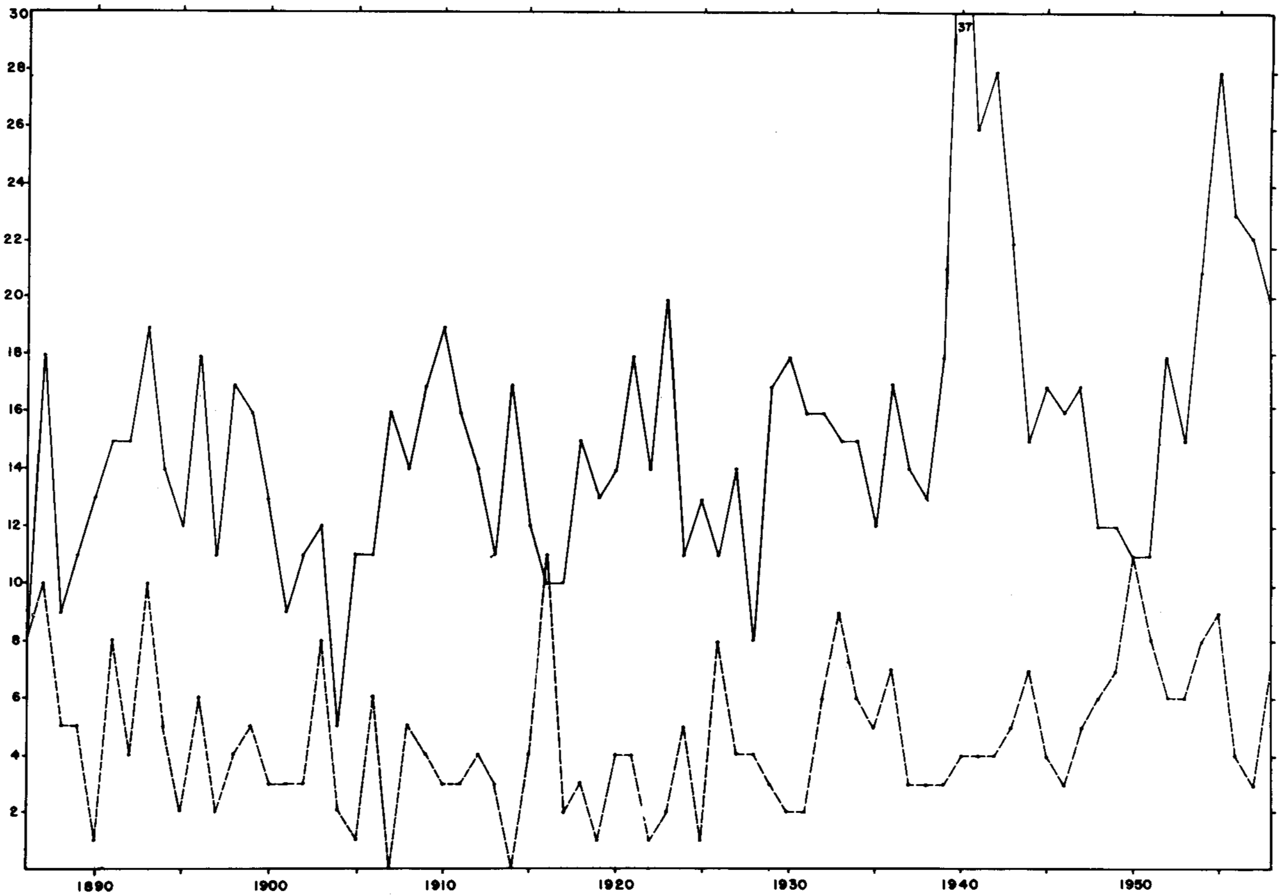

FIGURE 3.—A plot of the annual number of typhoons (solid curve) and hurricanes (dashed curve) for the period 1886–1958.

TABLE 1.—*A frequency distribution of the annual number of hurricanes (typhoons) for the Atlantic and Pacific areas and the regional divisions. The entries in the table are the actual number of years the individual values shown on the left were reported. G, C, and S refer to Gulf of Mexico, Caribbean, and South China Sea, and AI, AII, PI, PII, and PIII to the individual numbered regions within the Atlantic and Pacific areas (figs. 1 and 2).*

No. per year	Hurricanes (all areas)	Typhoons (all areas)	Atlantic regions				Pacific regions			
			G	C	AI	AII	S	PI	PII	PIII
0	2		36	29	11	28	2		48	25
1	4		23	28	27	25	20		8	27
2	7		10	10	15	15	15	1	3	14
3	14		3	5	6	2	11	1	4	2
4	14		1	1	8	2	12	3	1	3
5	9	1			3	1	5	5		1
6	7				3		3	8	3	1
7	4						1	4	1	
8	6	2					2	5	2	
9	2	2					2	8		
10	2	2						7		
11	2	10						6	1	
12		6						8		
13		5						6		
14		7						4		
15		7						5	1	
16		6						1		
17		7						1	1	
18		6								
19		2								
20		2								
21		1								
22		2								
23		1								
26		1								
28		2								
37		1								

correlation between the sunspot curve and the typhoon frequency curve during the period from 1900 to 1940 may be fortuitous.

4. REGIONAL TROPICAL CYCLONE ACTIVITY

The tropical cyclone frequencies for the four regions in the Atlantic and the Pacific have been used in an attempt to associate anomalous activity in the various areas. Five-year running means of the type shown in figure 4 were prepared for all the regions in the two ocean areas and correlation coefficients were computed from the annual frequency data for the individual regions.

In the Pacific, nearly two-thirds of the storms formed in Pacific I region (fig. 2). As would be expected, the general features of the curve of the overlapping 5-year means for this region are similar to those for the total typhoon curve (fig. 3). For this reason, this curve has not been reproduced. It was also felt that no purpose would be served in presenting the curve for the Pacific III region since the fluctuations are small and irregular. A frequency distribution of the number of typhoons in each of the regions is shown in table 1.

The 5-year overlapping means for the South China Sea and Pacific II regions (fig. 5) show several interesting

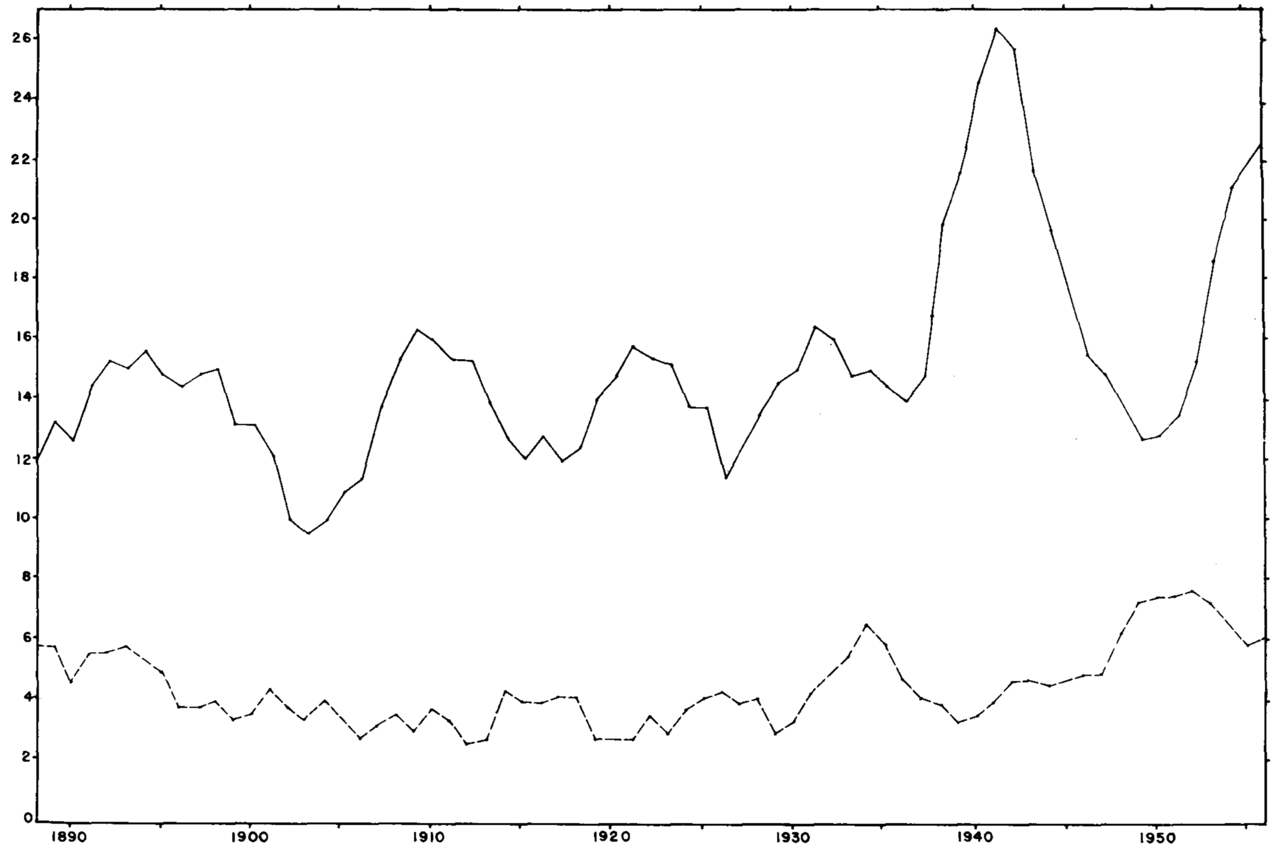

Figure 4.—A plot of the running 5-year mean frequency of typhoons (solid) and hurricanes (dashed) computed from the values plotted in figure 3.

and relatively large variations during the period of record. The activity in the South China Sea region is shown to be relatively steady except for the period prior to 1900. This curve appears very questionable and it would seem likely that many of the storms first reported in the South China Sea during this period actually formed farther east. Perhaps this change in the reported number of typhoons forming in the South China Sea can be accounted for by an increase in the amount of data from the area of the Philippines. Another feature which suggests that the earlier portion of the record should be treated with caution is the fact that there were no storms shown forming east of 145° E. (region II) before 1905.

The annual frequency of typhoons in region II has varied over a very large range. It would seem likely that during the peak periods in 1905–1910 and around 1918 the annual frequency was greater than reported in the record. This is suggested by the much higher values around 1940 and 1958 when observations were much more plentiful and by the fact that activity did not go to zero during periods of minimal activity as was shown in the earlier part of the record.

The marked maxima in 1940–1942 and 1957–1958 for the Pacific II region offer important contributions to the maxima shown during the same periods in the total typhoon curve (fig. 4). However, during both of these periods there was a slight increase in the number of storms forming in the Pacific I area.

The activity in the Atlantic I region constituted about 42 percent of the total number of hurricanes over the period of record. The curve of the overlapping means for this region has not been reproduced since there were very few extended periods of anomalous activity except for those corresponding to the major features of the Atlantic curve (fig. 3). The fluctuations are somewhat smaller in the regional curve with the means ranging from about 1 to 4 storms per year. The curve for the Caribbean is not shown since fluctuations are quite small and nothing in the nature of long period fluctuations is indicated. The activity in the Gulf of Mexico and in the Atlantic II regions was slightly more variable and the running means for these areas are shown in figure 5.

Comparison of the curves of the overlapping means for the various regions is perhaps helpful in detecting correlations between the longer-term trends in the various areas. However, these curves can be rather poor indicators of the degree of correlation between annual frequencies in the individual areas. For example, a negative correlation between activity in the Gulf of Mexico and the Atlantic II regions is suggested by the curves of figure 5, and the linear correlation coefficient computed from annual values read from the overlapping means was −0.27. However, the

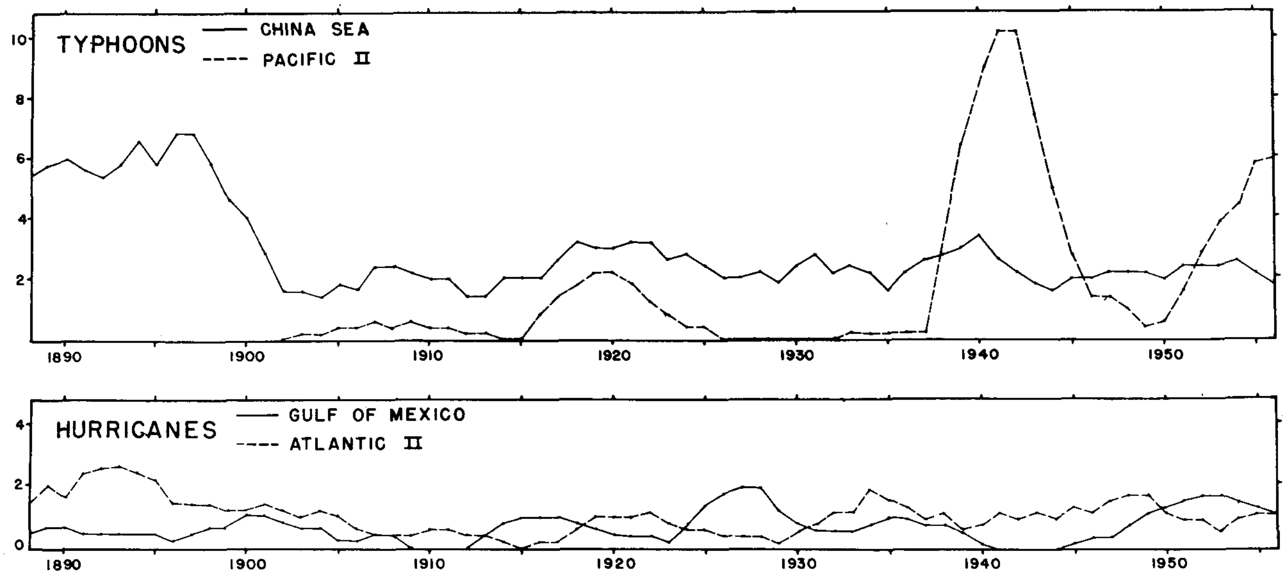

Figure 5.—Running 5-year mean frequency for the regions indicated.

correlation computed from the observed annual totals for the two areas was essentially zero.

The linear correlation coefficients between activity in the individual Atlantic regions range from +0.19 to −0.13. These extremely small values suggest there is little or no association between activity in the different regions. Since the seasonal distribution of hurricanes, as discussed below, is quite different in some of the regions, interregional correlation coefficients were computed for the August and September period when most hurricanes occur. These were different but were no higher than those previously mentioned.

The linear correlation coefficients for the individual Pacific regions are also very small except for a −0.40 value between activity in the South China Sea and Pacific I regions. Since we have questioned the accuracy of the early portion of the South China Sea record, this computation was repeated omitting the portion of the record prior to 1905. The correlation was smaller (−0.27) but was still much higher than any of the other values. In computing the values for the Pacific II region the period 1905–1958 was used since the earlier portion of the record is completely devoid of storms.

Correlation coefficients were also computed between the Atlantic and Pacific regions. The highest value obtained is a +0.18 between the Atlantic I and Pacific II regions. We can suggest no reason for a higher correlation between activity in these regions than between that in other regions and we are inclined to think that this value may be spurious. The correlation between the total activity in the Atlantic and Pacific, as mentioned above, is +0.04 and the correlation between the primary formation areas in the two oceans (Pacific I and Atlantic I) turned out to be −0.02.

This investigation of the variations of tropical cyclogenesis within the individual regions has not been very rewarding as far as establishing recurrent patterns or in associating activity in the various regions. The only areas which showed large fluctuations in the annual frequency of tropical cyclones were the Pacific II and, to a much smaller extent, the Gulf of Mexico regions (fig. 5). The linear correlation between activity in the individual regions was extremely small except for the South China Sea and Pacific II regions.

5. SEASONAL DISTRIBUTION OF TROPICAL CYCLONES

The tropical cyclone data for the Atlantic and Pacific areas have been examined in an attempt to determine if there are differences in the seasonal distribution of hurricanes and typhoons during years of unusually high and low activity. Before presenting these statistics, some of the prominent features of the mean seasonal distribution of storm activity for the 1886–1958 period will be summarized for the two ocean areas and for the regional subdivisions (table 2). In this table the mean monthly frequencies have been expressed in terms of percent of the mean annual frequency for each of the specified areas.

The Atlantic tropical cyclone activity is concentrated in the period August through October with nearly 85 percent of the storms occurring during this period (table 2). About 60 percent of the Pacific storms occur during this same 3-month period.

There are rather marked variations in the seasonal distribution of hurricanes in the four regions. These include the relatively high proportion of Gulf of Mexico storms in June and July, the very high proportion of Caribbean storms in October, and the fact that half of

TABLE 2.—*Mean monthly frequency of hurricanes and typhoons expressed in percent of the annual total for the individual areas. These statistics refer to tropical cyclones of hurricane intensity and means were taken for the period 1886–1958.*

ATLANTIC

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gulf of Mexico	----	----	----	----	----	19.6	12.5	28.6	25.0	14.3	----	----
Caribbean	----	----	----	----	----	7.6	7.6	13.6	25.8	39.4	6.1	----
Atlantic I	----	----	0.7	0.0	1.4	0.0	6.3	30.8	40.6	14.7	4.2	1.4
Atlantic II	----	----	----	----	----	----	----	31.1	50.0	13.5	4.1	1.4
All hurricanes	----	----	0.3	0.0	0.6	4.7	6.2	27.1	37.2	19.2	3.8	0.9

PACIFIC

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South China Sea	0.5	0.9	0.0	1.4	7.4	12.2	22.3	13.0	17.7	14.4	9.3	0.9
Pacific I	1.6	0.1	0.3	1.3	3.3	4.1	16.8	22.2	21.6	14.9	10.8	3.1
Pacific II	1.8	1.8	4.4	2.6	5.3	3.5	22.8	21.0	18.4	8.8	4.4	5.3
Pacific III	1.2	2.4	0.0	0.0	1.2	3.6	20.2	35.6	21.4	11.9	2.4	0.0
All typhoons	1.3	0.6	0.6	1.3	4.1	5.6	18.7	21.5	20.5	14.0	9.2	2.7

the Atlantic II hurricanes form in September. The bimodal character of the distribution in the Gulf of Mexico and the complete absence of activity prior to August in the Atlantic II region are also interesting features. These features have, of course, been pointed out by other investigators (cf. [4]).

The activity in the Pacific regions tends to be spread out through much more of the year and the contribution from the peak months is relatively small compared with some of the Atlantic regions. The mean July activity for all regions in the Pacific is appreciably higher than that in the Atlantic while, in terms of the percentages, the October activity is less. However, the decrease in activity between September and October is greater in the Atlantic than in the Pacific. The variations of the seasonal distributions in the individual regions from the mean of the whole area are considerably smaller in the Pacific than in the Atlantic data. A bimodal distribution is shown for the South China Sea, somewhat analogous to that for the Gulf of Mexico, and a rather marked August maximum is shown for the storms forming north of 25° N. (region III).

The first attempt to study differences in the seasonal distributions during periods of maximal and minimal activity made use of periods defined by the 5-year overlapping means. Four-year periods centered about each of the five most prominent peaks and troughs of the two curves in figure 4 were selected and averages were computed. The differences in the monthly distribution of storms during the maximal and minimal periods are very small. The differences are somewhat greater, especially in the Atlantic, if the maximal and minimal statistics are defined from the annual frequency data rather than from the overlapping means. In this second approach, we selected for each ocean area the individual years in which the annual frequency was greater or less than some arbitrary value. These values were selected so that about 20 percent of the years would be classified in the maximal and in the minimal category. The maximal and minimal data were computed in the case of hurricanes for years with 8 or more and 2 or fewer storms; for typhoons the numbers were 18 or more and 11 or fewer. The number of years involved varied from 12 to 18.

TABLE 3.—*Same as table 2 except mean monthly percentage frequency values refer to years of maximal and minimal activity during the 1886–1958 period as specified in the text.*

HURRICANES

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximal						5.1	10.2	27.6	35.7	16.3	4.1	1.0
Minimal						2.9	2.9	25.7	42.9	20.0	2.9	2.9

TYPHOONS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximal	1.6	1.6	1.0	2.3	5.0	5.3	21.4	20.8	21.1	8.6	6.9	4.3
Minimal	2.2	1.5	0.0	0.7	5.2	6.7	17.0	20.8	19.3	14.8	8.9	3.0

The mean percentages of hurricanes and typhoons forming during the individual months for the periods of maximal and minimal activity are shown in table 3. Statistics of this type are not presented for the regions since in many cases the number of storms was quite small during the minimal periods. However, some of the interesting features of the regional distributions during the maximal and minimal years, defined in terms of activity in the complete area, are presented.

The differences between the seasonal distribution in the maximal and minimal years and between these and the mean distribution for the complete record (table 2) are extremely small in the Pacific data. The greatest difference is in the October data where the activity during the maximal years is about 5 percent below the long-term average.

The Atlantic data suggest that there is a slight difference in the seasonal distribution of hurricanes during the years of high and low frequency. This is most marked in the increased relative frequency of June and July storms in the maximal data. The data for the minimal years are very little different from the mean of the complete record (table 2) except that the August-October peak is a little more pronounced.

Most of the increased activity in July during the years of highest frequency did not come from the Gulf of Mexico where, in the mean, July storms are most frequent, but from the Atlantic I region where July activity is relatively rare. During the maximal years, hurricanes in the Atlantic I region were nearly as frequent in August as in September while in the minimal years September storms were four times as frequent as August storms. June and July activity was shown in the Caribbean in the maximal sample but was completely lacking in the minimal data. The number of cases involved in most of the regional distributions was rather small and some of the differences noted above probably have no significance.

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